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(54) **Apparatus and method for extracting edges and lines**

Gerät und Verfahren zum Bestimmen von Konturen und Linien

Appareil et méthode d'extraction de contours et de lignes

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Description

This invention relates to image processors, and more particularly to an image enhancing apparatus and method for detecting edges and lines.

The vast quantity of data available in the form of aerial, satellite and other types of imagery far exceeds the processing capacity of current computing environments. Consequently, there exists a need for systems that can rapidly and automatically detect objects given large quantities of imagery, representing unpredictable scenes and objects.

The tasks of computer vision systems fall generally into three classes: low level, middle level and high level. Low level analysis involves decomposing the raw image into easily manipulatable visual primitives such as regions and lines and their attributes such as color, texture, size, shape, orientation, length, etc. The middle level process is concerned with analyzing the lines and regions found in the low level process and finding, for example, certain geometric shapes and patterns. High level analysis operates on the extended geometric features to arrive at a recognition and description of the objects in the scene.

The present invention is concerned primarily with improvements in low level image processing. The raw image input for low level processing typically comprises intensity changes in an image that are due in part to reflectance, depth, orientation and illumination discontinuities. The organization of significant local intensity changes (edges) into more coherent global events (lines or boundaries) is an early but important step in the transformation of the visual signal into useful intermediate constructs for middle and upper level interpretative processes. Over the past twenty years a number of methods have been developed for edge detection. These include:

1) a simple thresholded convolution (e.g. Sobel operator, Roberts cross operator) within a fixed sized two dimensional window followed by a "thinning" operation on the resulting data;

2) a Laplacian operator within a two dimensional processing window coupled with an algorithm to detect "zero-crossings";

3) the Haralick facet model algorithm; and

4) the Nevatia-Babu algorithm.

An algorithm for generating linked edge boundaries between adjacent regions of different gray levels is disclosed in an article entitled "Contextual Boundary Formation by One-Dimensional Edge Detection and Scan Line Matching" by Ehrich et al. in COMPUTER GRAPHICS AND IMAGE PROCESSING, vol. 16, No. 2 (June, 1981). An edge detector generates data structures representing alternative interpretations of edge cross sections. The edge hypotheses are linked together to form global edges based on the strength of the matches between the edge hypotheses. In detail, relational trees are formed with respect to assumed edge points along a scan line. The used matching algorithm is a parallel tree matching algorithm that matches the relational trees of the edges in adjacent scan lines. The linking is achieved by examining several linking possibilities and using a procedure that determines the optimal linking arrangement based upon the strength of the matches between the various assumed edge points.

Even with these and other current methods, the generation of line segments has remained a difficult problem requiring time consuming edge chaining and line segmenting algorithms. Thus, it would be desirable to provide a technique for generating edges and line segments that is faster and more accurate than previous methods.

Besides slowness, the above techniques for edge detection have a number of other drawbacks. For example, images having a variety of resolutions and contrasts are difficult to handle due to the use of a fixed two dimensional window or patch. There are two problems resulting from the use of a fixed window: 1) when an edge is larger than the window, you get either no edge or multiple edges; and 2) if a window is too large, it blurs details by averaging data within the window. While using multiple window sizes is one approach to this problem, the complexity of sorting out the resulting data from the various window sizes has limited the usefulness of that technique. As a result, it would be desirable to provide an image processor that can handle image features of many different resolutions equally well with fewer spurious or missed edges.

A related problem caused by a fixed two dimensional window size is the resulting sensitivity to thresholds. If a window size is too small, only a part of an edge is measured. The convolution then gives a measure of only part of the intensity change, and a threshold set to detect the intensity change of an entire edge would be too high and would ignore the edge. Decreasing the threshold would result in multiple edges where only a single edge exists. Consequently, it would be desirable to provide an image processor that can properly discriminate between high and low contrast image features without being too sensitive to the threshold setting.

The present invention as set out in claims 1 and 9 provides an image enhancing apparatus and method that rapidly and accurately detects edges and straight line segments from image data. The invention performs a one dimensional, rather than two dimensional, analysis of image data and it results in an effectively dynamic, rather than static, window size to ensure that the whole edge is captured. It does this by the use of a series of horizontal and/or vertical scan lines to search for one dimensional edge signatures in the scan line intensity data. Edge curvature points in the scan line intensity da-

ta are analyzed to determine if they have certain features characteristic of edges. Once identified, pairs of these curvature points which represent edge boundaries are then used to determine single point edge locations. This may be done by finding the average intensity level between the pairs of curvature points and designating that point as the edge location. This process, in effect, sets the window size dynamically and permits edges of many different resolutions and contrasts to be analyzed.

After a point edge location is determined, point edge locations on successive scan lines may be tracked to form straight line segments. This is accomplished by setting a range for a possible line segment direction from a first point and determining if a point edge location in the next scan line is within that range. If it is, a line segment is drawn between the first and second points and the permissible range is narrowed for each edge point in succeeding scan lines until an edge point no longer fits within the permissible range. Edges falling outside a given line segment direction may then used to begin new line segments.

This entire process requires only one or two passes through the image data. Two passes could be performed simultaneously with a parallel processing architecture. The result is the extraction of edge points and line segments from digitized image data much faster than with previous comparable methods.

The invention handles image features of many different resolutions equally well. Also, edge and line segment data is extracted more "clearly" so that lines are less fragmented, with fewer spurious or missed edges. In many images the edge threshold parameter is less critical than in previous methods and properly discriminates between high and low contrast image features. The invention could also be used to detect and track other intensity features beside edges such as certain features having characteristic combinations of edges such as coastlines, roads, or vehicles. Also, the invention could be used to detect features having certain defined spectral characteristics.

The various advantages of the present invention will become apparent to one skilled in the art by reading the following specification and by reference to the following drawings in which:

FIG. 1 is a perspective view of a series of pixel intensity curves along successive scan lines of representative image data;

FIG. 2 is a graph of a single pixel intensity curve for successive pixels along a single scan line in accordance with the present invention;

FIG. 3 is a graph of a portion of the pixel intensity curve shown in FIG. 2 showing the derivation of an edge point from two curvature extrema;

FIG. 4 is an illustration of the method of forming the line segments by tracking edge points in accordance with the present invention; and

FIG. 5 is a diagram of an image processing system in accordance with the present invention.

FIG. 1 represents a two dimensional signal (i.e. an image). The x and y axes are the horizontal and vertical axes of the image while the third axis represents the intensity (brightness) of the digitized image at each point (pixel). The source of the image may be light or other regions of the electromagnetic spectrum; or it could be an acoustic image or any other desirable two dimensional signal. As a specific example, the digitized image might be obtained from a CCD sensor connected to a frame grabber that digitizes the CCD signal output and produces a 512 x 512 array of pixel intensity values. These values would be automatically stored in computer memory. It should be noted that, for clarity, FIG. 2 shows only 32 pixel intensity points. However, if a 512 x 512 element CCD sensor is used, a given scan line would actually have 512 pixel intensity points.

In accordance with the present invention, the intensity value of each pixel on the pixel intensity curve 10 is represented by intensity points 12. It will be appreciated that the intensity data is plotted pictorially in FIGS. 1 and 2, as an illustrative aid. In practice, the methods of the present invention may be carried out by performing various calculations on the data without actually plotting the data. Likewise, the term "scan" will be used to indicate analysis of data along a particular vertical or horizontal line and does not necessarily imply any mechanical scanning motion across the image.

The present invention involves a two part procedure to arrive at line segments from image data. The first part involves the detection of edge points. The second part involves the tracking of the detected edge points to form straight lines. It will be appreciated that once the edge points have been detected, the edge points will provide information that may be used in a number of ways. However, in the preferred embodiment, it is preferred that the edge points determined by the first part of the invention then be used to arrive at line segments in accordance with the second part of the invention.

In the first part of the present invention, the detection of edge points is carried out as a one dimensional process. Initially, the intensity data such as that shown in FIG. 2 is analyzed for intensity signatures that are characteristic of edges. This may be accomplished by first processing the data with a sliding difference operator to obtain local "slopes" at each point 12 along the scan line intensity curve 10. In particular, for a given point 14 on the intensity curve 10 the slope of the line connecting that point 14 with the previous point 16 is determined. Likewise, for a succeeding point 18 the slope of a line connecting that point 18 with the previous point 14 is determined. The first derivative slopes are then converted to angles, or "angle slopes", using the function:

$$\text{angle} = \tan^{-1}(c \times \text{slope})$$

where c is a constant (less than 1) such as .75. The value chosen for c is not very critical. It acts as a vertical gain or amplification of the pixel intensities and is set to allow convenient integer tabular representation of the angle function.

A sliding difference of angle slopes may then be taken to obtain a slope curvature at each point along the scan line. For example, at a first point 14 the slope curvature will be equal to the angle slope at the second point 18 minus the angle slope at the first point 14.

Next, curvature extrema are located. Curvature extrema represent points on the intensity curve 10 which have maximum positive or negative local slope curvatures. In FIG. 2 curvature extrema are represented by the circled points 20. The determination of which curvatures are extrema is accomplished by comparing the magnitudes of a consecutive sequence of curvatures possessing common sign. It can be seen by inspection of FIG. 2 that curvature extrema points 20 represent points where there are relatively large changes in the slope between the curvature extrema points 20 and the preceding and succeeding points. In other words, curvature extrema are places where trends of intensity change undergo major alteration. It is this rapid alteration of intensity (or shading) trends that characterize the two sides of edge boundaries in image data. This is shown in FIG. 3.

It should be noted that in some systems noise from the sensor or other sources may introduce peaks or spikes that have nothing to do with the image being analyzed. Unfortunately, such noise spikes will possibly be interpreted as curvature extrema. In order to effectively filter out such noise all curvature extrema can be checked to see if they exceed a noise threshold. This noise threshold may be chosen to be proportional to the slopes of the scan line intensity curve at the points where the extrema are located. Curvature extrema which exceed the threshold may then be ignored since they likely represent noise. It will be appreciated that the threshold will depend on many characteristics of the system and of the image data involved and in systems that are not susceptible to unacceptable noise levels the step of comparing the curvature extrema to the noise threshold may be omitted entirely.

The next step is to confirm the existence of an edge from the curvature extrema points 20. Since the curvature extrema points 20 are determined by the data itself, the invention, in effect, sets a dynamic window size from which to find edges. From FIG. 2 it can be seen that the intensity difference between the first curvature extrema 20 at the extreme left and the second curvature extrema 20 is fairly small: while the difference in intensity between the second curvature extrema 20 and the third is much greater. One may interpret this to mean that an edge exists somewhere between the second and third curvature extrema 20, but that a surface of relatively uniform intensity (and hence no edge) exists between the first and second curvature extrema 20. Accordingly, to detect edges the intensity level at each curvature extrema 20 is compared to that at each neighboring curvature extrema 20. Where the difference exceeds a predetermined threshold an edge is confirmed.

This procedure is depicted in more detail in FIG. 3. Here, a portion of the intensity curve 10 is shown having two curvature extrema 20. The intensity level at the first curvature extrema 20 is labeled I_1. The intensity at the second is I_2. An edge is confirmed if the change in intensity, $I_2 - I_1$ exceeds a predetermined threshold. In some cases it is possible for the difference between the intensity levels to exceed the threshold even where there is no edge. This may occur, for example, in the case of an extended region of gentle shading, where the total change in intensity level from one side of the region to the other is fairly large but no edge exists between the two extrema. To prevent an edge from being found in a region of gentle shading, when the intensity difference between two neighboring curvature extrema are found to exceed the predetermined threshold, the average intensity change per pixel may be checked. If the average intensity change per pixel is less than a predetermined amount, for example, one intensity unit, then it can be concluded that the region does not contain an edge but instead may be a region of gradual intensity change. In such cases no edge will be found between those curvature extrema.

Once the existence of an edge is confirmed between two curvature extrema 20, the point edge location can then be determined. This may be done by finding the average intensity level between the two curvature extrema 20. That is, the intensity level equal to $(I_1 + I_2)/2$, is found. The pixel corresponding to that average intensity level on the intensity curve 10 is then determined. The location of this pixel along the scan line is then labeled an edge point. The above procedure is repeated for each curvature extremum point 20 throughout the entire intensity curve 10 for a given scan line.

To begin forming line segments in accordance with the second part of the present invention, the entire procedure described above is repeated for a second scan line. Once edge points are found in the second scan line they can be compared to edge points in the preceding scan line to determine if a line segment can be drawn between edge points in the first and the second scan lines using the procedure described below. The line forming process is then repeated for all subsequent parallel scan lines.

In more detail, in accordance with the present invention, as each scan line is processed and rendered into a set of elected edge points, the edge points are tracked as if they were uniform velocity targets. The edge points extracted from a given scan line are associated with edge points detected in previous scan lines according to the following three rules:

1) when a detected edge point lies within "n" pixels of an edge point on the previous scan line where

the point on the previous line is not already associated with a straight line segment, use the two detected edge points to initiate a straight line segment.

2) when a detected edge point does not lie within "n" pixels of an edge point on the previous scan line and it also cannot be associated with an existing straight line segment, save the location of the detected edge for the starting point of a new line segment.

3) when a detected edge point lies within "n" pixels of a predicted edge point location (where the prediction was made using knowledge of the line segments currently being tracked) attempt to add the new edge point to the appropriate line segment in the manner as described below.

The selection of "n" is not critical and it will be appreciated that the exact number can be optimized by trial and error. For example "n" in some configurations may be chosen to be 1 or 2 pixels.

Referring now to FIG. 4, the procedure for adding to an existing line segment is illustrated. Note from Rule 1 above that the first two edge points may be used to initiate a straight line segment. From these two points an initial projected line segment direction is computed. This is labeled "first estimate of line segment direction" in FIG. 4. An "error bar" of a predetermined number of pixels (typically 1 or 2 pixels) is also assigned to the second point. This bar is used to determine the range within which the line segment direction can be adjusted as later points are added to the line segment. The idea is to permit some fluctuation of the actual position of edge points along the line segment to which they belong. On the other hand, the points must not be permitted to slowly drift off the initial line segment direction resulting in an arc instead of a straight line.

FIG. 4 also shows a third point being added to the line segment. Since the third point falls within the permissible line segment range (it is between the first upper limit and the first lower limit of line segment direction) it passes the criterion which determines that it is part of the line segment and not the start of some new line. The error bars assigned to the third point are used to establish a new and tighter range within which the line segment direction can be adjusted. This range is shown in FIG. 4 as defined by the lines labeled "second upper limit on line segment direction" and "second lower limit on line segment direction". Note that the second lower limit on line segment direction coincides with the first lower limit on line segment direction, thus effectively narrowing the new limits on line segment direction. The second estimate of line segment direction is taken to be from the first point to the third and newest point.

Finally, a fourth point is considered. As FIG. 4 illustrates, the fourth point falls outside the range of the second upper and lower limits on line segment direction. Thus, the fourth point cannot be added to the line segment. The tracking of the line segment is terminated at the third point and the location of the fourth is saved as the possible starting location of a new line segment.

It is noteworthy that both the first part of the invention (edge detection) and the second part (line segment formation) can be performed on each scan line before proceeding to subsequent scan lines. As a result, only one pass through the vertical scan lines and one pass through the horizontal scan lines is necessary. Moreover, since the vertical and horizontal scanning processes are entirely decoupled, the two passes through the data could be performed simultaneously, for example with a parallel processing architecture. In such cases the normal steps required to parallelize algorithms need not be done due to the fact that the vertical and horizontal scans are inherently separable. These features contribute to the increased speed of processing of the present invention.

There are a number of ways to separate the respective role of the vertical and horizontal scan lines to avoid redundancy and to further enhance the speed and accuracy of the invention. In this regard, it should be noted that both vertical and horizontal scans are desirable but both are not absolutely necessary. Useful line segment information can be derived from either set of scans. However, it is desirable to have both because a vertical line scan cannot process a vertical image line and a horizontal scan cannot handle a horizontal image line. Consequently, it is preferred that the roles of the vertical and horizontal scans be divided so that each has its respective "sphere of influence". For example, each set of scans may handle line segments that have a range of plus or minus 45°. Specifically, horizontal scans may handle line segments in a vertical direction and 45° on either side of vertical; vertical scans may handle line segments along a horizontal direction and also 45° on either side of horizontal. As a result, the processing will not track line segments outside the permitted range even though it would be capable of doing so.

A minor consideration is that at exactly 45° there is some ambiguity and the possibility exists that both sets of scans would ignore the 45° line segment as belonging to the other set of scan lines. Consequently, it is preferred to have the horizontal and vertical jurisdictions overlap slightly even at the risk of occasionally double counting a line.

It will be appreciated that the data produced will consist of coordinates of line segment points from vertical and horizontal scans. These may be used independently or combined. The line segment data may be plotted for visual inspection or it may be used directly in subsequent middle and higher level image analysis.

Referring now to FIG. 5, a simplified diagram of an image processing system 22 in accordance with one embodiment of the present invention is shown. A sensor 24, which may be a CCD array, receives signals of varying intensity from an image. The sensor converts the raw signal to an electrical signal which is transmitted to a preprocessor 26. This preprocessor 26 may perform

such functions as frame grabbing and digitizing for example. The digitized signal is then transmitted to a processor 28 which includes an IO unit 30, a CPU 32 and memory 34. Once the image data is received and stored in memory 34, the processor 28 may then perform the necessary calculations on the data to arrive at the edge and line locations using the techniques outlined above. Finally, the coordinate locations of the edge and line segments may be sent from the processor 28 to a display unit 36 where they may be utilized in the desired manner.

It will be appreciated that the present invention is very amenable to hardware implementations. As mentioned previously, the decoupled nature of the vertical and horizontal scans makes parallelizing the two tasks relatively simple. Also, since the processing is approached as a one dimensional signal problem it could readily be handled by a pipeline type processor with digital signal processing chips. As a result, known and readily available low cost hardware can be used to implement the present invention.

Preliminary tests have been conducted using images ranging from 512 x 512 pixels to 200 x 200 pixels square. Each pixel of the images had an intensity ranging from 0 to 255 units. The images included both visible and infrared data. Test image scenes included highly cluttered imagery with features 2 to 3 pixels apart; very low and very high contrast features with intensity variations ranging from 6 to 130 units; mixed feature resolutions with feature boundaries ranging from 4 pixels sharp to 25 pixels blurred; and small and large features ranging from under 4 pixels along the largest dimension to over 300 pixels along the largest dimension. Both timing tests and line quality tests were run on the invention which was implemented on a MicroVAX II computer. The invention took 60 seconds to extract edges from a 512 x 512 image of a beverage can and another 30 seconds to obtain the straight line segments. By comparison, a state-of-the-art edge extraction algorithm (the Nevatia-Babu algorithm) took 24 minutes to extract edges on the same beverage can test image. The invention was shown to handle blurred lines very well. A comparison with other state-of-the-art algorithms showed that they failed badly in their ability to handle blurred lines.

Claims

1. An apparatus for enhancing an image containing features, said image represented by pixel data, including feature as well as non-feature pixel data, said enhancement being produced without prior knowledge of said features, said apparatus comprising:

    sensor unit (24) for converting light energy from discrete pixels in said image into electrical signals, said pixels having defined locations in the X-Y plane;
    preprocessor unit (26) for digitizing said signals;
    means (28) for identifying curvature extrema as those points on a scan line where the intensity undergoes relatively large changes with respect to previous and subsequent pixels;
    means (28) for measuring the difference in intensity between pairs of curvature extrema and identifying those pairs of curvature extrema for which said difference exceeds a predetermined threshold;
    means (28) for identifying individual edge points as a point along the scan line between said identified pairs for curvature extrema,
    means (28) for identifying edge points along neighboring scan lines, first and second edge points being on first and second neighboring scan lines;
    means (28) for extrapolating a line segment between said first edge point and said second edge point if the pixel location difference between the first edge point on the first scan line and the second edge point on the second scan line is less than n pixels, where n is an integer;
    means (28) for calculating upper and lower line direction limits by extrapolating a line from said first edge point to a point X pixels greater than said second point, where X is an integer, and by extrapolating a line from said first edge point to a point X pixels less than said second point;
    means (28) for extrapolating a new line segment between said first edge point and a third edge point on a neighboring third scan line if that third edge point lies within said upper and lower line direction limits; and
    display unit (36) for creating an enhanced image containing only said identified edge points and line segments, wherein said enhanced image contains predominantly edge points and lines representing said features and is relatively free of said non-feature pixels.

2. The apparatus of claim 1 wherein said scan lines are vertical as well as horizontal scan lines.

3. The apparatus of claim 1 or 2 further comprising a means (28) for comparing said curvature extrema for each point with a second predetermined threshold that is proportional to the slope curvature for that point and means for ignoring those curvature extrema which exceed said second threshold, whereby noise in said pixel data is ignored.

4. The apparatus of claim 1, 2 or 3 further comprising a means (28) for comparing the average intensity change per pixel between neighboring curvature extrema and comparing this value with a third pre-

determined threshold wherein if said third threshold is not exceeded an edge point will not be identified between said curvature extrema.

5. The apparatus of anyone of the preceding claims, comprising memory unit (34) for storing said digitized signals, and means (32) coupled to said memory unit for detecting and measuring the intensity of said signals at discrete pixels along a plurality of scan lines throughout said image, said intensity values creating an intensity curve along the scan lines.

6. The apparatus of anyone of the preceding claims comprising means (28) for assigning the value of said electrical signal for each pixel to each defined location, and means (28) for selecting one linear scan line of said pixels in the X-Y plane.

7. The apparatus of anyone of the preceding claims wherein said means (24) for converting light energy is a CCD imager.

8. The apparatus of anyone of the preceding claims wherein said preprocessor unit (26) is a frame grabber preprocessor.

9. A method for enhancing an image containing features, said image represented by pixel data, including feature as well as non-feature pixel data, said enhancement being produced without prior knowledge of said features, said method comprising the steps of:

a) converting light energy from an image into electrical signals corresponding to the intensity of said light energy in discrete pixels in said image, said pixels each having a defined location in the X-Y plane;
b) identifying curvature extrema in a scan line by determining those pixels for which said electrical signal values change most rapidly with respect to the values for neighboring pixels along said scan line;
c) measuring the difference in the magnitude of said electrical signal value between all pairs of curvature extrema along said scan line;
d) determining selected pairs of curvature extrema for which said difference exceeds a predetermined threshold;
e) identifying as an edge point a pixel along the scan line having an electrical signal value between the value for said identified pair, said pixel being located between said identified pair along said scan line; and displaying the X-Y location of said edge point;
f) identifying edge points along neighboring scan lines, first and second edge points being along first and second neighboring scan lines;
g) extrapolating a line segment between said first edge point and said second point if the pixel location difference between the first edge point on the first scan line and the second edge point on the second scan line is less than n pixels, where n is an integer;
h) calculating upper and lower line direction limits by extrapolating a line from said first edge point to a point X pixels greater than said second point, where X is an integer, and by extrapolating a line from said first edge point to a point X pixels less than said second point; and
i) extrapolating a new line segment between said first edge point and a third edge point on a neighboring third scan line if that third edge point lies within said upper and lower line direction limits.

10. The method of claim 9 wherein said step of converting light energy further comprises the step of providing a CCD sensor (24) for converting said light energy.

11. The method of claim 9 or 10 further comprising the steps of digitizing said electrical signal into a digital signal for each pixel value.

12. The method of claim 11 further comprising the step of transmitting said digitized signals to a programmable processor (26) and storing said intensity values in memory locations corresponding to pixel coordinates in said image.

13. The method of anyone of claims 9 to 12 wherein said step b) further comprises the step of determining those points where the derivative of the intensity curve exceeds a second threshold.

14. The method of anyone of claims 9 to 13 wherein said step e) further comprises the step of determining the point having an intensity value equal to the average intensity of the identified pair of curvature extrema.

15. The method according to anyone of claims 9 to 14 further comprising a step (j) of calculating a new upper or lower line direction limit by extrapolating a line from said first point to a point X pixels greater than said third edge point and by extrapolating a line from said first point to a point X pixel less than said third edge point, and using only those direction limits which create a narrower range of line direction limits.

16. The method of claim 15 further comprising the steps of:

(k) repeating steps (g) - (j) for a forth and all

succeeding edge points in each succeeding scan line until no edge point is found within the current upper and lower direction limits; and
(l) repeating steps (f) - (k) for edge points that fall outside upper and lower limits to create new line segments.

Patentansprüche

1. Vorrichtung zum Verstärken eines Bildes, das Merkmale enthält, wobei das Bild durch Bildelementdaten dargestellt ist, die Bildelementdaten sowohl von Merkmalen als auch von Nichtmerkmalen beinhalten, wobei die Verstärkung ohne vorhergehende Kenntnis der Merkmale erzeugt wird, wobei die Vorrichtung aufweist:

   eine Sensoreinheit (24), die Lichtenergie von diskreten Bildelementen in dem Bild in elektrische Signale wandelt, wobei die Bildelemente definierte Stellen in der X-Y-Ebene aufweisen;

   eine Präprozessoreinheit (26), die die Signale digitalisiert;

   eine Einrichtung (28), die Krümmungsextrema als solche Punkte auf einer Abtastzeile identifiziert, an denen die Intensität relativ große Änderungen bezüglich vorhergehenden und nachfolgenden Bildelementen erfährt;

   eine Einrichtung (28), die die Differenz der Intensität zwischen Paaren von Krümmungsextrema mißt und solche Paare von Krümmungsextrema identifiziert, für welche die Differenz einen vorbestimmten Schwellwert überschreitet;

   eine Einrichtung (28), die einzelne Randpunkte als einen Punkt entlang der Abtastzeile zwischen den identifizierten Paaren für Krümmungsextrema identifiziert,

   eine Einrichtung (28), die Randpunkte entlang benachbarten Abtastzeilen identifiziert, wobei erste und zweite Randpunkte auf ersten und zweiten benachbarten Abtastzeilen liegen;

   eine Einrichtung (28), die ein Liniensegment zwischen dem ersten Randpunkt und dem zweiten Randpunkt extrapoliert, wenn die Bildelementstellendifferenz zwischen dem ersten Randpunkt auf der ersten Abtastzeile und dem zweiten Randpunkt auf der zweiten Abtastzeile weniger als n Bildelemente beträgt, wobei n eine Ganzzahl ist;

   eine Einrichtung (28), die durch ein Extrapolieren einer Linie von dem ersten Randpunkt zu einem Punkt, der X Bildelemente größer als der zweite Punkt ist, wobei X eine Ganzzahl ist, und durch ein Extrapolieren einer Linie von dem ersten Randpunkt zu einem Punkt, der X Bildelemente kleiner als der zweite Punkt ist, obere und untere Linienrichtungsgrenzen berechnet;

   eine Einrichtung (28), die ein neues Liniensegment zwischen dem ersten Randpunkt und einem dritten Randpunkt auf einer benachbarten dritten Abtastzeile extrapoliert, wenn dieser dritte Randpunkt innerhalb der oberen und unteren Linienrichtungsgrenzen liegt; und

   eine Anzeigeeinheit (36), die ein verstärktes Bild erzeugt, das lediglich die identifizierten Randpunkte und Liniensegmente enthält, bei der das verstärkte Bild vorwiegend Randpunkte und Linien enthält, die die Merkmale darstellen, und relativ frei von Bildelementen von Nichtmerkmalen ist.

2. Vorrichtung nach Anspruch 1, bei der die Abtastzeilen sowohl vertikale als auch horizontale Abtastzeilen sind.

3. Vorrichtung nach Anspruch 1 oder 2, die desweiteren eine Einrichtung (28), die die Krümmungsextrema für jeden Punkt mit einem zweiten vorbestimmten Schwellwert vergleicht, der proportional zu der Steigungskrümmung für diesen Punkt ist, und eine Einrichtung aufweist, die solche Krümmungsextrema, welche den zweiten Schwellwert überschreiten, ignoriert, wodurch Rauschen in den Bildelementdaten ignoriert wird.

4. Vorrichtung nach Anspruch 1, 2 oder 3, die desweiteren eine Einrichtung (28) aufweist, die die mittlere Intensitätsänderung pro Bildelement zwischen benachbarten Krümmungsextrema vergleicht und diesen Wert mit einem dritten Schwellwert vergleicht, bei der, wenn dieser dritte Schwellwert nicht überschritten wird, kein Randpunkt zwischen diesen Krümmungsextrema identifiziert wird.

5. Vorrichtung nach einem der vorhergehenden Ansprüche, die eine Speichereinheit (34), die die digitalisierten Signale speichert, und eine an die Speichereinheit gekoppelte Einrichtung (32) aufweist, die die Intensität der Signale an diskreten Bildelementen entlang einer Mehrzahl von Abtastzeilen durch das Bild hindurch erfaßt und mißt, wobei die Intensitätswerte eine Intensitätskurve entlang der Abtastzeilen erzeugen.

6. Vorrichtung nach einem der vorhergehenden Ansprüche, die eine Einrichtung (28), die den Wert des

elektrischen Signals für jedes Bildelement jeder definierten Stelle zuweist, und eine Einrichtung (28) aufweist, die eine lineare Abtastzeile der Bildelemente in der X-Y-Ebene auswählt.

7. Vorrichtung nach einem der vorhergehenden Ansprüche, bei der die Einrichtung (24), die die Lichtenergie wandelt, ein CCD-Bildsensor ist.

8. Vorrichtung nach einem der vorhergehenden Ansprüche, bei der die Präprozessoreinheit (26) ein Bildfangpräprozessor ist.

9. Verfahren zum Verstärken eines Bildes, das Merkmale enthält, wobei das Bild durch Bildelementdaten dargestellt ist, die Bildelementdaten sowohl von Merkmalen als auch von Nichtmerkmalen beinhalten, wobei die Verstärkung ohne vorhergehende Kenntnis der Merkmale erzeugt wird, wobei das Verfahren die folgenden Schritte aufweist;

   a) Wandeln von Lichtenergie von einem Bild in elektrische Signale, die der Intensität der Lichtenergie in diskreten Bildelementen in dem Bild entsprechen, wobei die Bildelemente alle eine definierte Stelle in der X-Y-Ebene aufweisen;

   b) Identifizieren von Krümmungsextrema in einer Abtastzeile durch Bestimmen solcher Bildelemente, für welche sich die Werte des elektrischen Signals bezüglich den Werten für benachbarte Bildelemente entlang der Abtastzeile am schnellsten ändern;

   c) Messen der Differenz des Betrags des Werts des elektrischen Signals zwischen allen Paaren von Krümmungsextrema entlang der Abtastzeile;

   d) Bestimmen ausgewählter Paare von Krümmungsextrema, für welche die Differenz einen vorbestimmten Schwellwert überschreitet;

   e) Identifizieren eines Bildelements entlang der Abtastzeile, das einen Wert des elektrischen Signals zwischen dem Wert für das identifizierte Paar aufweist, als einen Randpunkt, wobei das Bildelement zwischen dem identifizierten Paar entlang der Abtastzeile liegt; und Anzeigen der X-Y-Stelle des Randpunktes;

   f) Identifizieren von Randpunkten entlang benachbarter Abtastzeilen, wobei erste und zweite Randpunkte entlang erster und zweiter benachbarter Abtastzeilen liegen;

   g) Extrapolieren eines Liniensegments zwischen dem ersten Randpunkt und dem zweiten Punkt, wenn die Bildelementstellendifferenz zwischen dem ersten Randpunkt auf der ersten Abtastzeile und dem zweiten Randpunkt auf der zweiten Abtastzeile weniger als n Bildelemente beträgt, wobei n eine Ganzzahl ist;

   h) Berechnen oberer und unterer Linienrichtungsgrenzen durch ein Extrapolieren einer Linie von dem ersten Randpunkt zu einem Punkt, der X Bildelemente größer als der zweite Punkt ist, wobei X eine Ganzzahl ist, und durch ein Extrapolieren einer Linie von dem ersten Randpunkt zu einem Punkt, der X Bildelemente kleiner als der zweite Punkte ist; und

   i) Extrapolieren eines neuen Liniensegments zwischen dem ersten Randpunkt und einem dritten Randpunkt auf einer benachbarten dritten Abtastzeile, wenn dieser dritte Randpunkt innerhalb der oberen und unteren Linienrichtungsgrenzen liegt.

10. Verfahren nach Anspruch 9, bei dem der Schritt eines Wandelns von Lichtenergie desweiteren den Schritt eines Vorsehens eines CCD-Sensors (24) aufweist, der die Lichtenergie wandelt.

11. Verfahren nach Anspruch 9 oder 10, das desweiteren die Schritte eines Digitalisierens des elektrischen Signals in ein digitales Signal für jeden Bildelementwert aufweist.

12. Verfahren nach Anspruch 11, das desweiteren den Schritt eines Sendens der digitalisierten Signale zu einem programmierbaren Prozessor (26) und eines Speicherns der Intensitätswerte in Speicherstellen aufweist, die den Bildelementkoordinaten in dem Bild entsprechen.

13. Verfahren nach einem der Ansprüche 9 bis 12, bei dem der Schritt b) desweiteren den Schritt eines Bestimmens jener Punkte aufweist, an denen die Ableitung der Intensitätskurve einen zweiten Schwellwert überschreitet.

14. Verfahren nach einem der Ansprüche 9 bis 13, bei dem der Schritt e) desweiteren den Schritt eines Bestimmens des Punktes aufweist, der einen Intensitätswert aufweist, der gleich der mittleren Intensität des identifizierten Paares von Krümmungsextrema ist.

15. Verfahren nach einem der Ansprüche 9 bis 14, das desweiteren einen Schritt (j) eines Berechnens einer neuen oberen oder unteren Linienrichtungsgrenze durch ein Extrapolieren einer Linie von dem ersten Punkt zu einem Punkt, der X Bildelemente größer als der dritte Randpunkt ist, und durch ein

Extrapolieren einer Linie von dem ersten Punkt zu einem Punkt, der X Bildelemente kleiner als der dritte Randpunkt ist, und eines Verwendens lediglich jener Richtungsgrenzen aufweist, welche einen schmäleren Bereich von Linienrichtungsgrenzen erzeugen.

16. Verfahren nach Anspruch 15, das desweiteren die folgenden Schritte aufweist:

(k) Wiederholen der Schritte (g) - (j) für einen vierten und alle nachfolgenden Randpunkte in jeder nachfolgenden Abtastzeile, bis kein Randpunkt innerhalb der momentanen oberen und unteren Richtungsgrenzen festgestellt wird; und

(l) Wiederholen der Schritte (f) - (k) für Randpunkte, die außerhalb von oberen und unteren Grenzen fallen, um neue Liniensegmente zu erzeugen.

Revendications

1. Appareil pour rehausser une image contenant des éléments caractéristiques, ladite image, qui est représentée par des données de pixels, contenant des données des pixels caractéristiques ainsi que non caractéristiques, ledit rehaussement étant produit sans connaissance préalable desdits éléments caractéristiques, ledit appareil comprenant:

une unité (24) à capteur pour convertir de l'énergie lumineuse provenant de pixels discrets de ladite image en signaux électriques, lesdits pixels ayant des positions définies dans le plan X-Y ;
une unité (26) de prétraitement pour numériser lesdits signaux;
un moyen (28) pour identifier des extréma de courbure constitués par les points d'une ligne de balayage où l'intensité subit des variations relativement importantes par rapport à des pixels précédents et suivants;
un moyen (28) pour mesurer la différence d'intensité entre des paires d'extréma de courbure et identifier les paires d'extréma de courbure pour lesquelles ladite différence dépasse un seuil prédéterminé;
un moyen (28) pour identifier des points de bord individuels comme étant un point le long de la ligne de balayage entre lesdites paires identifiées pour des extréma de courbure,
un moyen (28) pour identifier des points de bord le long de lignes de balayage voisines, des premier et second points de bord se trouvant sur des première et seconde lignes de balayage voisines,
un moyen (28) pour extrapoler un segment de ligne entre ledit premier point de bord et ledit second point de bord si la différence de position de pixel entre le premier point de bord, sur la première ligne de balayage, et le second point de bord, sur la seconde ligne de balayage, est inférieure à n pixels, où n est un entier,
un moyen (28) pour calculer les limites supérieure et inférieure de direction de ligne par extrapolation d'une ligne dudit premier point de bord à un point supérieur de X pixels audit second point, où X est un entier, et en extrapolant une ligne à partir dudit premier point de bord à un point inférieur de X pixels audit second point;
un moyen (28) pour extrapoler un nouveau segment de ligne entre ledit premier point de bord et un troisième point de bord sur une troisième ligne de balayage voisine si ce troisième point de bord se situe en deçà desdites limites supérieure et inférieure de direction de ligne; et
une unité (36) d'affichage pour créer une image rehaussée ne contenant que lesdits points de bord et lesdits segments de ligne identifiés, ladite image rehaussée contenant de façon prédominante des points de bord et des lignes représentant lesdits éléments caractéristiques et étant sensiblement exempte de pixels non caractéristiques.

2. Appareil selon la revendication 1, dans lequel lesdites lignes de balayage sont des lignes de balayage verticales ainsi qu'horizontales.

3. Appareil selon la revendication 1 ou 2, comprenant en outre un moyen (28) pour comparer lesdits extréma de courbure en chaque point avec un second seuil prédéterminé qui est proportionnel à la courbure de la pente en ce point, et un moyen pour ignorer les extréma de courbure qui dépassent ledit second seuil, de façon que le bruit contenu dans lesdites données de pixels soit ignoré.

4. Appareil selon la revendication 1, 2 ou 3, comprenant en outre un moyen (28) pour comparer la variation d'intensité moyenne par pixel entre des extréma de courbure voisins, et pour comparer cette valeur à un troisième seuil prédéterminé, de telle sorte que si ledit troisième seuil n'est pas dépassé, un point de bord ne sera pas identifié entre lesdits extréma de courbure.

5. Appareil selon l'une quelconque des revendications précédentes, comprenant une unité (34) à mémoire pour stocker lesdits signaux numérisés et un moyen (32) relié à ladite unité à mémoire pour détecter et mesurer l'intensité desdits signaux en des pixels

discrets le long d'un ensemble de lignes de balayage parcourant ladite image, lesdites valeurs d'intensité créant une courbe d'intensité le long des lignes de balayage.

6. Appareil selon l'une quelconque des revendications précédentes, comprenant un moyen (28) pour affecter la valeur dudit signal électrique en chaque pixel à chaque position définie, et un moyen (28) pour sélectionner une ligne de balayage linéaire desdits pixels dans le plan X-Y.

7. Appareil selon l'une quelconque des revendications précédentes, dans lequel ledit moyen (24) de conversion d'énergie lumineuse est un capteur à CCD.

8. Appareil selon l'une quelconque des revendications précédentes, dans lequel ladite unité (26) de prétraitement est un préprocesseur de carte de numérisation d'images.

9. Procédé pour rehausser une image contenant des éléments caractéristiques, ladite image, qui est représentée par des données de pixels, comportant des données de pixels caractéristiques ainsi que non caractéristiques, ledit rehaussement étant produit sans connaissance préalable desdits éléments caractéristiques, ledit procédé comprenant les étapes qui consistent:

a) à convertir de l'énergie lumineuse provenant d'une image en signaux électriques correspondant à l'intensité de ladite énergie lumineuse dans des pixels discrets de ladite image, lesdits pixels ayant chacun une position définie dans le plan X-Y ;
b) à identifier des extréma de courbure dans une ligne de balayage en déterminant les pixels pour lesquels lesdites valeurs du signal électrique varient le plus rapidement par rapport aux valeurs de pixels voisins le long de ladite ligne de balayage;
c) à mesurer la différence, en valeur absolue, dudit signal électrique entre toutes les paires d'extréma de courbure le long de ladite ligne de balayage;
d) à déterminer des paires sélectionnées d'extréma de courbure pour lesquelles ladite différence dépasse un seuil prédéterminé;
e) à identifier en tant que point de bord un pixel, le long de ligne de balayage, ayant une valeur de signal électrique comprise entre la valeur déterminée pour ladite paire identifiée, ledit pixel étant situé entre ladite paire identifiée le long de ladite ligne de balayage; et à afficher la position X-Y dudit point de bord;
f) à identifier des points de bord le long de lignes de balayage voisines, des premier et second points de bord se trouvant le long de première et seconde lignes de balayage voisines,
g) à extrapoler un segment de ligne entre ledit premier point de bord et ledit second point de bord si la différence de position de pixel entre le premier point de bord, sur la première ligne de balayage, et le second point de bord, sur la seconde ligne de balayage, est inférieure à n pixels, où n est un entier;
h) à calculer les limites supérieure et inférieure de direction de ligne par extrapolation d'une ligne dudit premier point de bord à un point supérieur de X pixels audit second point, où X est un entier, et en extrapolant une ligne dudit premier point de bord à un point inférieur de X pixels audit second point; et
i) à extrapoler un nouveau segment de ligne entre ledit premier point de bord et un troisième point de bord sur une troisième ligne de balayage voisine si ce troisième point de bord se situe entre lesdites limites supérieure et inférieure de direction de ligne.

10. Procédé selon la revendication 9, dans lequel ladite étape qui consiste à convertir de l'énergie lumineuse comprend en outre l'étape qui consiste à utiliser un capteur (24) à CCD pour convertir ladite énergie lumineuse.

11. Procédé selon la revendication 9 ou 10, comprenant en outre les étapes qui consiste à numériser ledit signal électrique en un signal numérique pour chaque valeur de pixel.

12. Procédé selon la revendication 11, comprenant en outre l'étape qui consiste à transmettre lesdits signaux numérisés à un processeur (26) programmable et à stocker lesdites valeurs d'intensité en des emplacements de mémoire qui correspondent à des coordonnées de pixels dans ladite image.

13. Procédé selon l'une quelconque des revendications 9 à 12, dans lequel ladite étape (b) comprend en outre l'étape qui consiste à déterminer les points où la dérivée de la courbe d'intensité dépasse un second seuil.

14. Procédé selon l'une quelconque des revendications 9 à 13, dans lequel ladite étape (e) comprend en outre l'étape qui consiste à déterminer le point ayant une valeur d'intensité égale à l'intensité moyenne de la paire identifiée d'extréma de courbure.

15. Procédé selon l'une quelconque des revendications 9 à 14, comprenant en outre une étape (j) qui consiste à calculer une nouvelle limite supérieure ou inférieure de direction de ligne en extrapolant une ligne dudit premier point à un point supérieur de X

pixels audit troisième point de bord et en extrapolant une ligne dudit premier point à un point inférieur de X pixels audit troisième point de bord, et à n'utiliser que les limites de direction qui créent une gamme plus étroite de limites de direction.

16. Procédé selon la revendication 15, comprenant en outre les étapes qui consistent :

(k) à répéter les étapes (g) - (j) pour un quatrième point de bord et tous les points suivants dans chaque ligne de balayage suivante jusqu'à ce qu'aucun point de bord ne soit trouvé entre les limites supérieure et inférieure de direction courantes; et

(l) à répéter les étapes (f) - (k) pour des points de bord qui se situent au-delà des limites supérieure et inférieure afin de créer de nouveaux segments de lignes.

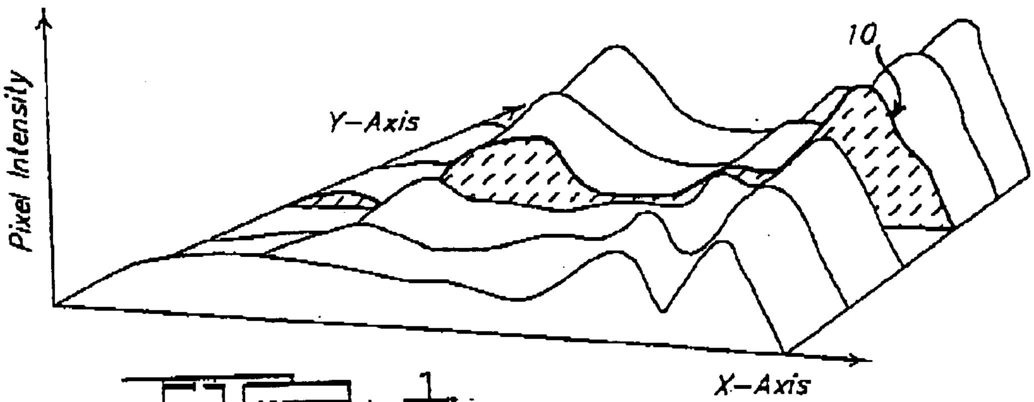

FIG. 1.

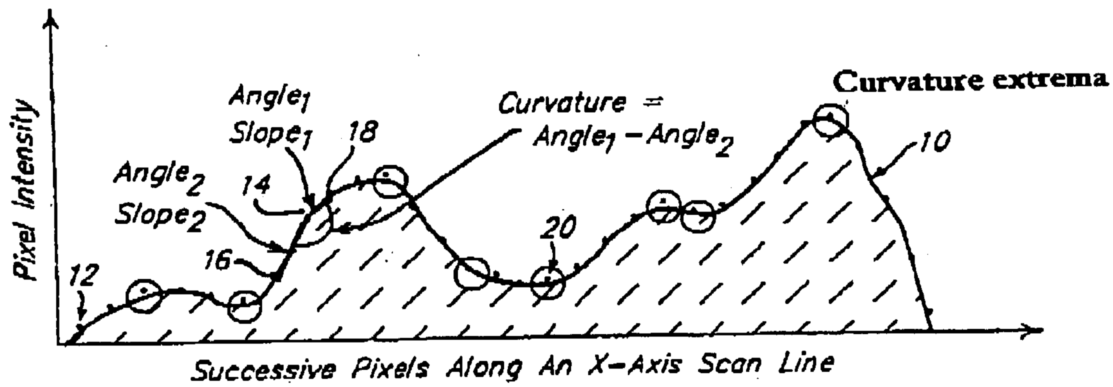

FIG. 2.

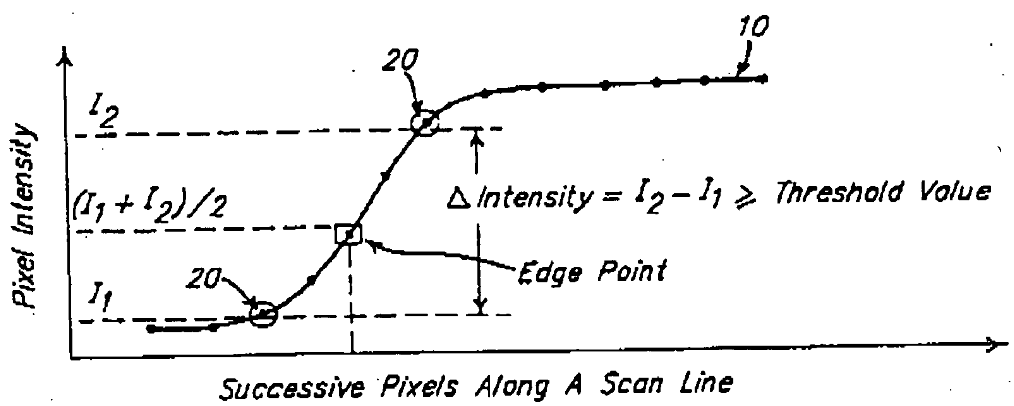

FIG. 3.

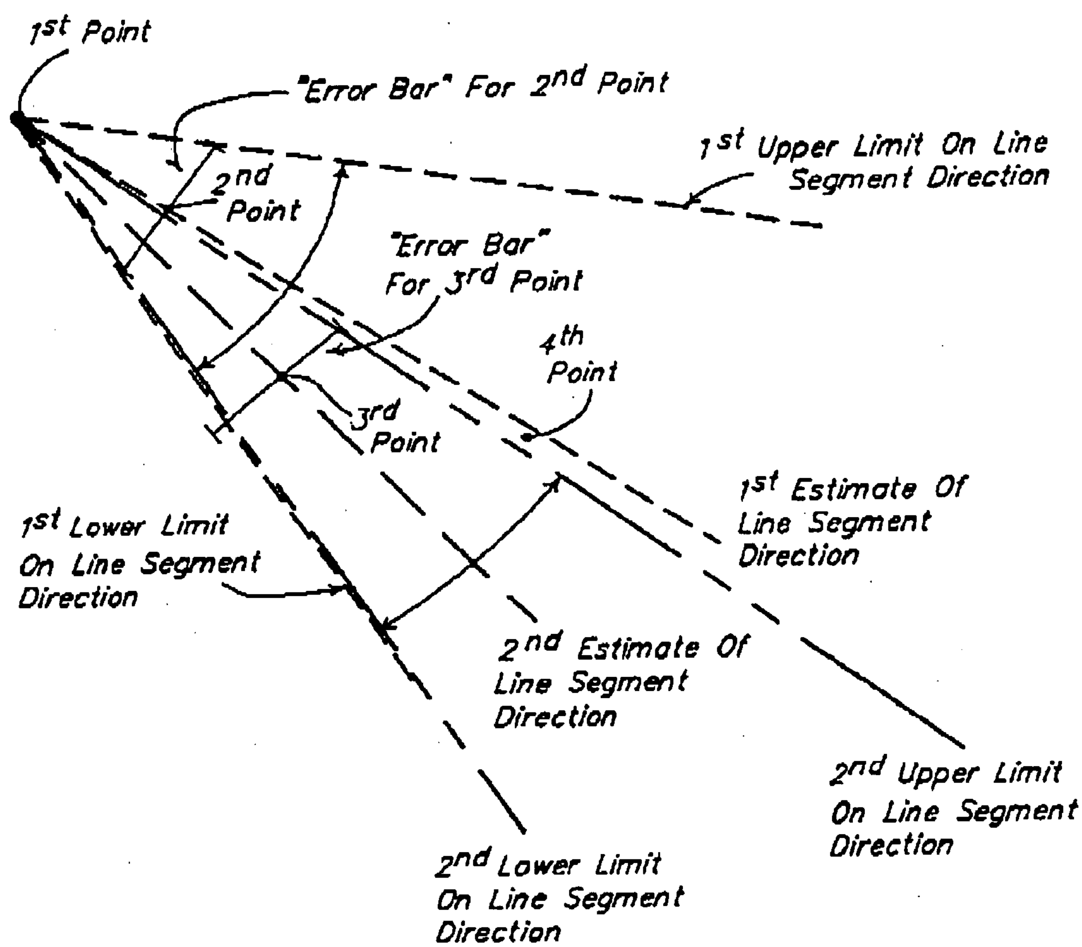
1st Point
"Error Bar" For 2nd Point
1st Upper Limit On Line Segment Direction
2nd Point
"Error Bar" For 3rd Point
4th Point
3rd Point
1st Estimate Of Line Segment Direction
1st Lower Limit On Line Segment Direction
2nd Estimate Of Line Segment Direction
2nd Upper Limit On Line Segment Direction
2nd Lower Limit On Line Segment Direction

FIG. 4.

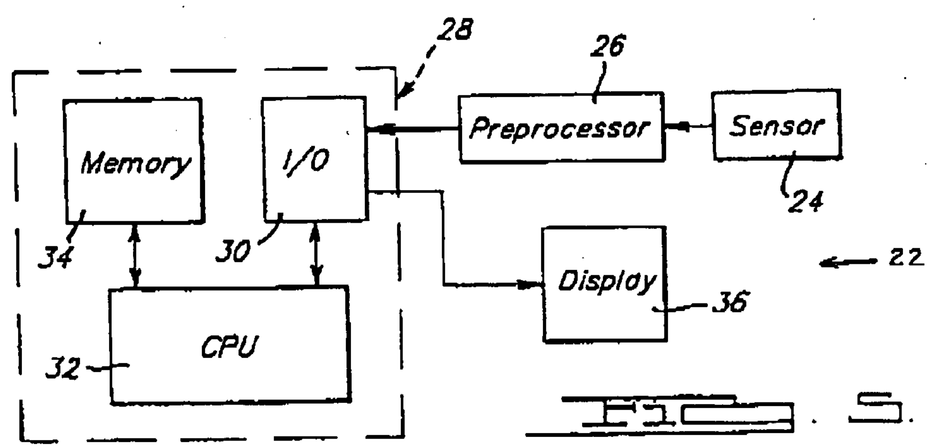
28
26
Preprocessor
Sensor
Memory
I/O
24
34
30
22
Display
36
32
CPU

FIG. 5.

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